Report

of the

Renaissance Operations Automation

Action Team

Review Draft

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Chartered by the

Renaissance Systems Engineering Working Group

Renaissance Operations Automation Action Team

Report Outline

June 30, 1995

1. Planning and Scheduling (P&S) Operations
- **1.1 Science Planning and Scheduling**
- **1.2 Spacecraft Planning and Scheduling (including user network P&S)**

2. Command Management Operations

3. Flight Operations
- **3.1 Health and Safety Monitoring and Anomaly Resolution**
- **3.2 Command and Control**

4. Orbit and Attitude Operations
- **4.1 Orbit Determination Daily Support**
- **4.2 Acquisition Data and Orbit-Dependent Product Generation**
- **4.3 Attitude Support and Attitude-Dependent Product Generation**
- **4.4 Sensor and Actuator Calibration**
- **4.5 Orbit Maneuver Support**

5. Data Collection, Processing, and Distribution Operations

6. Prelaunch Test (I&T) and Simulation Operations
- **6.1 Spacecraft Integration and Test (I&T) Support**
- **6.2 MOC Integration Testing**
- **6.3 Network and Launch Site Testing**
- **6.4 FOT Training**

Introduction

This is the final report of the Renaissance Operations Automation Action Team. The action team was chartered by the Renaissance Systems Engineering Working Group to analyze opportunities and develop recommendations for achieving increased levels of operations automation in Renaissance second generation systems. This introduction describes the process used to create this report, and the format of the operations automation analyses that comprise the body of the report.

Process

The action team used the following process to produce this report:

1. Define Scope – The action team obtained guidance from the Renaissance Systems Engineering Working Group to define the scope of this study. The action team was directed to identify operations functions that should be targeted for full or partial automation in the Renaissance 2nd generation systems, which are planned for implementation 2-3 years from now. The capabilities of current AI systems, and those expected to be available in 1-2 years, should support the targeted automation.

2. Identify Operations Categories – Team members developed a set of operations categories to be analyzed. The categories were then organized into the report outline.

3. Allocate Categories – Each operations category was allocated to a team member who served as the focal point for research and information gathering for that category. This team member became the author of the operations automation analysis write-up for that category.

4. Develop Operations Automation Analysis Write-ups – Each author gathered material from personal research and from other individuals in his home organization, and prepared the first three sections of the analysis (as described below). Draft write-ups were distributed among the team members via email, hard copy, and posting in the action team folder on the Renaissance server.

5. Critique Write-ups – Each write-up was reviewed by the team and critiqued. The review included suggestions for inclusion of missing information.

6. Develop Recommendations – The principal author prepared recommendations for operations automation for Renaissance. Recommendations were reviewed by the entire action team and modified to achieve consensus.

7. Assess Recommendations – The principal author assessed the potential impact of each recommendation; the assessments were reviewed by the entire action team.

Operations Automation Analyses

The body of this report is comprised of a set of operations automation analyses, organized into six major sections. Each analysis treats one category of ground system operations. Each analysis identifies the principal author(s), and conforms to the following outline:

A. Description – This section briefly describes the operations category, identifying at a high level the activities performed and their context.

B. State of the Practice at GSFC – This section describes how operations in this category are performed at GSFC today, and how automation is being introduced. The discussion is divided into three subsections:

B.1 Operator Functions and Operational Systems – This subsection describes the functions currently performed by GSFC operators, and the systems used to support those functions.

B.2 Planned Systems – This subsection describes planned systems that will soon automate some of the operations functions described in B.1.

B.3 Possible Systems – This subsection describes future operations automation systems or extensions to current systems that are already being considered at GSFC, but are still in the research or evaluation phase.

C. State of the Practice at Other Organizations Relevant to GSFC – This section describes the level of operations automation in this operations category outside GSFC, at organizations that have similar mission requirements (e.g. NASA JPL, NASA JSC, Intelsat, and NRL).

D. Issues – This section discusses key issues relevant to operations automation in this operations category for Renaissance 2nd generation missions. Issues include:

- **Identification of opportunities for operations automation at GSFC**
  - **where GSFC is behind the state of the practice at other organizations**
  - **desires for automation expressed by GSFC operations staff**
- **Maturity of technology required to achieve desired automation.**
- **Impact of new operations concepts.**

E. Recommendations – This section enumerates operations automation recommendations to the Renaissance Systems Engineering Working Group regarding this operations category.

Renaissance Operations Automation Action Team
Bill Potter – 4/18/95

1. Planning and Scheduling Operations

1.1 Science Planning and Scheduling

A. Description

Science scheduling is dependent upon the type of mission and the length of science to be performed. There are currently three types of missions that GSFC fly to date. They are survey, pointing, and hybrids which are a combination of the two. Length of science is determined on number of science campaigns, availability of resources, such as spacecraft, length of mission, and length of observations. There may be more than the ones I have identified, but I believe you will get the idea as we move on.

Science planning and scheduling is generally based on a 28 day planning cycle. This coincides with NCC and DSN schedules since they are on a 4 week cycle. Other science plans may differ from this planning cycle. Science plans consist of resources and activities. Since the science mission may consist of several instruments there are two levels of planning that take place. The first level is at the instrument team level. At this level the instrument team plans out their activities that must occur before they can participate in science campaigns. This may include calibrations or software loads. The next level is the construction of the science plan. At this level all the instrument plans are merged to produce the science plan. This plan then is distributed to all the instrumenters and observatories involved in a particular campaign.

B. State of the Practice at GSFC

B.1 Operator Functions and Operational Systems

Currently, the planning and scheduling system operators provide daily inputs to the planning systems. The types of inputs needed are contact times (received from a scheduling source, such as, DSN or NCC, etc.), attitude and orbit predicts, power, tape recorder/SSR information, daily spacecraft activities, and science activities, etc. Before the spacecraft launches the operator constructs a database/knowledge base which contains the types of activities, and their associated rules and constraints, that will be needed during the mission. This does not mean that they cannot add additional activities. Once the spacecraft has launched there have been many instances where activities and resources have changed. The process of builing a knowledge base takes several months. It is similar to building to constructing a project data base. Once the knowledge base is in place the operator begins to plan the daily activities for each observation day. The operator only needs to examine the plan to ensure that all activities have been accounted for. The operator also has the option of editing the plan if needed.

B.2 Planned Systems

Currently, Code 510 has a development effort underway that will provide a reusable planning and scheduling system to all the flight teams at Goddard and to NASA centers. This tool is called MOPSS. This tool will provide the generic capabilities of planning and scheduling that currently exist. This tool does not provide a revolutionary change but an evolutionary change. MOPPS is currently being written in C++. It will no longer use a flat file as the knowledge base. Instead, it will use a database to access the activity information. MOPSS is planned to be integrated into the MOC environment. However, MOPSS is being built to stand alone so that it can provide planning support for other missions that do not use the MOC concept. Scientist are one example.

B.3 Possible Systems

It will be very difficult to eliminate planning and scheduling from operations. The basic premise is that the spacecraft needs to have goals in order to accomplish the mission. The goals are set by the scheduler. Without the scheduler another method of setting goals is needed. A way to do this is to say that the spacecarft mission is to meet certain criteria and once that criteria has been met the mission is over. Some where in the operations a human is going to have to make a decision.

C. State of the Practice at Other Organizations

The three primary places that currently have on-going planning and scheduling work are JPL, University of Colorado, and HST science Institute. There are some good scheduling ideas. Most approaches are rational and should be investigated. The institutions utilize the same methods as used at Goddard. However, JPL has a different mission than Goddard. There is benefit though to sharing existing models, software, or designs.

D. Issues

E. Recommendations

Renaissance Operations Automation Action Team
Jacqueline Rybacki – 5/24/95

1.2 Spacecraft Planning and Scheduling

B. State of the Practice at GSFC

The Planning and Resource Reasoning Tool Expert System (PARR)

PARR is an expert software system for automated scheduling. It is applied to a variety of scheduling tasks. GSFC has been using PARR to support mission operations since 1987. Currently, PARR is used to support the Earth Radiation Budget Satellite (ERBS) for scheduling of TDRSS contacts and by the Extreme Ultra-violet Explorer (EUVE) for scheduling TDRSS contacts and for spacecraft health and safety activities. PARR is used for scheduling astronauts' activities during the servicing missions for the Hubble Space Telescope (HST). Other uses of PARR are scheduling HST ground resources and for scheduling flight operations team activities for the Solar and Heliospheric Observatory (SOHO).

PARR use reduces operational costs. This expert system has been proven to create better schedules faster and cheaper than other automated scheduling systems. In most cases, PARR eliminates the need for an expert scheduler, or at the least, reduces the amount of time scheduling experts require to create schedules. PARR alleviates the under utilization of key resources.

Not all scheduling problems may be sutitable for complete automation. Unusual cases should require human operator intervention. Even when PARR cannot automatically create a schedule, it continues to provide assistance for the human expert by providing instantaneous feedback of violated scheduling constraints. It will also, at the user's direction, find appropriate ways to resolve scheduling conflicts introduced when a scheduler adds or deletes a schedule activity.

The start-up costs for most automated scheduling system can be considerable. The start-up costs of PARR are lower than most automated scheduling systems because it does not require a tool expert to build the system knowledge base that involves lengthy interviews with domain experts. Because PARR schedules the way human experts schedule, they find it easy to understand its' inputs and make modifications.

Our past experience indicates that after a few short training sessions, an experienced scheduler can enter rules into PARR for scheduling. Also, PARR can operate effectively with partial rule sets, thus this expert system can be acceptance tested and introduced into the operational environment quickly.

PARR runs on UNIX-based workstations an on Sun Sparc, IBM RS/6000 and Hewlett-Packard 9000 workstations. Currently, three versions of PARR are available.

The base version includes an interactive user interface based on X-Windows and Motif. The user can manipulate the schedule graphically by modifying a PERT-chart-like depiction. It also provides an interface for modifying the constraints, strategies, and resources.

When it is more appropriate to deal with the scheduling system through the use of files, a batch version, BPARR, is used. It provides all of PARR's scheduling and constraint checking capabilities through a file-based interface.

Finally, PARR is available as a C++ object-oriented class library that can be linked into another program.

Renaissance Operations Automation Action Team
Joe Valenti – 5/21/95

2.0 Command Management Operations

A. Description

The Command Management System (CMS) allows the Flight Operations Team (FOT) to manage the usage of Absolute Time Processor (ATP) and Relative Time Processor (RTP) memory in the On-Board computer (OBC) and create command, memory, table, and flight software loads that are uplinked to the spacecraft. The CMS receives and preprocesses high-level command request files, converting command requests to spacecraft command bit patterns and builds stored command loads for the spacecraft from time-ordered binary command sequences. It validates and constraint checks the loads and schedules them for uplink.

B. State of the Practice at GSFC

B.1 Operator Functions and Operational Systems

Until the late eighties, CMSs were developed and operated on IBM mainframes in a Command Management Facility (CMF) with a team of operations personnel assigned to run the software using input collected from the experimenters and flight teams. With the advent of the ISTP WIND/POLAR, UARS and EUVE systems, the CMS was de-institutionalized and was developed to be run on powerful workstations incorporating windows technology to support extensive data handling requirements and more effective, user-friendly interactive displays. This allowed the CMS to be run completely by the FOT, in a distributed environment, with no CMF operator intervention.

CMS Functions

Using mission planning aids (ground station contacts and orbital event information) received from the FDF and the DSN, the CMS creates and stores <u>events</u> for each ground station contact and orbital event extracted from these files. The CMS allows the FOT to manually create, edit, and delete events. COBE, WIND/POLAR, SOHO, UARS and SMEX CMSs provided this functionality. The SMEX CMSs allow the FOT to create, edit, and delete events using a graphical user interface.

CMS complexity was reduced with the incorporation of the "trigger" mechanism. Triggers provide event-based commanding. Events, extracted from the FDF/DSN-provided files and manually created by the FOT, are applied to the triggers. If the event satisfies the trigger's conditions, the trigger's commands are assigned absolute time-tags, relative to the event. The resulting absolute time-tagged commands are added to the activity plan. Further improvement was introduced with the SMEX CMSs. The trigger editing user interface was greatly enhanced by providing the FOT with a graphical user interface to define a trigger.

Additionally, the SWAS CMS permits trigger definitions to be specified in an ASCII file. Using this mechanism, the SAOSOC provides the CMS with science commands that have their time-tags determined by ground station contact and orbital events. With other missions, science command files contained absolute time-tagged commands. The SWAS CMS approach allows science commands to be time-tagged with the latest ground station contact and orbital event data available.

Using the CMS, the FOT defines <u>activities</u>. An activity is a group of commands. On many missions a group of commands is called a macro. Activities can be added directly to an Absolute Time Sequence (ATS) command load or generated into a Relative Time Sequence (RTS) command load. Missions such as COBE, WIND/POLAR, and UARS, provided this functionality.

However, a big improvement was introduced with the SMEX CMSs. The activity editing user interface was greatly enhanced by providing the FOT with a graphical user interface to select commands, set/adjust the command's execution time, and set/adjust command sub-mnemonic values. In addition, the SMEX CMSs allow the user to define parameters for an activity that can have their values assigned when the activity is added to an ATS load or when the activity is generated into an RTS.

The CMS generates <u>science instrument loads</u>. The CMS receives science instrument image load files from the Science Operations Center (SOC), generates science instrument load files, and transfers the science instrument load files to the POCC. On many CMSs (FAST, SOHO at least), this process requires no FOT intervention.

The CMS receives <u>table and memory load image files</u> from the Flight Software Maintenance Element (FSME), generates these files into table and memory load files (ASCII to binary conversion) and transfers them to the POCC. SOHO and SMEX CMSs and others provide this capability.

The CMS receives <u>table and memory dump files</u> from the POCC, generates these files into table and memory dump image files (binary to ASCII conversion), and transfers them to the FSME. SMEX CMSs provide this capability.

On many missions the CMS generates <u>special loads</u>. These include thruster tables (WIND/POLAR) and star catalogs (UARS).

The CMS allows the FOT to create and generate <u>ATS command loads</u>, and transfer generated ATS command loads to the POCC. A big improvement was introduced with the SMEX CMSs. On many other missions, the FOT created a command list using a command syntax language and a text editor. The load editing user interface was enhanced even further by providing the FOT with a graphical user interface to select commands, set/adjust the command's execution time, and set/adjust command sub-mnemonic values.

The CMS allows the FOT to create and generate RTS command loads, and transfer generated RTS command loads to the POCC.

CMS Execution Environment

On COBE, the CMS was executed by the CMF (multi-mission) on mainframe computers in batch mode. SOC, FOT, and FDF provided command lists to the CMF analyst personnel. The command lists were merged, a load was generated, and transferred to the POCC (multi-mission). The GRO CMS was also mainframe resident and was used in a similar manner.

On UARS, SOHO, and WIND/POLAR, the CMS is executed by the FOT (single-mission) on workstations. This move eliminated the CMF and made it interactive, thus drastically reducing the turnaround time between receipt of command inputs and load transfer.

On SMEX missions, the SAMPEX, FAST, and SWAS CMSs are executed by a SMEX FOT (multi-mission). Each FOT member is cross trained in the other SMEX missions. Each SMEX CMS is developed with a common user interface to minimize the cross training impact. This move eliminated the single mission/single FOT philosophy used by UARS, SOHO, and WIND/POLAR.

B.2 Planned Systems

The SOHO CMS currently under development is adding some unique features in addition to the above. They are developing an effective near-real-time commanding capability (throughput mode), a process to run near-real-time commanding unattended (the FOT doesn't even have to be logged on), and an interactive graphical timeline for planning and scheduling.

Throughput mode allows a PI who is local to the Experimenter Operations Facility (EOF) to issue commands and view status relating to the commands in near-real-time. In addition it allows the uplink of large instrument table loads from a background queue.

The planning and scheduling timeline provides a graphical display of the scheduling status from the activity plan and allows the FOT to perform various functions associated with scheduling. These functions include selection of primary vs. alternate activity plans, selection of operational period to perform scheduling, selection of local inputs to schedule for uplink, schedule time-tagged load for uplink, reserve dedicated time periods, check for schedule conflicts, resolve conflicts, re-segment the activity plan, delete obsolete activity plan, and request for scheduling reports. The display includes zoom control and horizontal and vertical scroll, among its many features. In addition, up to five alternate versions of the activity plan may be maintained.

With the advent of the XTE, TRMM, ACE, and Landsat Mission Operations Centers (MOCs), the CMS as a separate entity will no longer exist, as such. Its functionality is being incorporated into the off-line portion of the MOC, and will be

accessed through a common user interface along with the real-time functions of the control center.

Along with the latest technology, the new CMSs are being developed with reuse in mind. The SMEX CMS series is now achieving very high levels of reuse and has a SMEX generic library of common software components which should be considered as building blocks in the Renaissance era. The SOHO CMS is also incorporating existing software components such as MOPSS (TRMM), checker (WIND/POLAR CMS), BPARR (Allied Signal), LEXX/YACC parsers (COTS).

B.3 Possible Systems

Future trends include continuing to develop a single CMS for families of satellites (e.g., ISTP, SMEX, XTE/TRMM), using UNIX-based workstations which are platform independent, using more commercial communications interfaces (TCP/IP), moving towards a prime shift only for FOT running of all normal planning and load generation activities, more automated commanding, load generation, and constraint checking, continued standardization of user interface look and feel, increased graphics, more standard reusable components, more combining of ground system elements onto one platform, and more support for telescience.

MOCA

MOCA is a systems engineering task chartered with reducing life cycle costs of missions. It is currently looking at moving capabilities normally performed on the ground to the spacecraft in an attempt to reduce flight operations costs. Among the CMS ideas explored are the following:

Install a spacecraft command language processor onboard the spacecraft to perform many of the CMS functions currently performed on the ground. High level commands would be sent directly to the spacecraft by the PIs. The ground segment of the CMS would only packet the PI and housekeeping commands for uploading. The savings here is not on implementation but in operations. The FOT would be the passive observer of the CMS loading and would only react if something fails.

Much of the housekeeping could be done onboard the spacecraft with smarter processors which would reduce the number of housekeeping commands generated on the ground and uploaded by the CMS.

The goal of MOCA is to have an operator-less system. All ground functions would occur automatically. Ideally, if a problem occurs onboard the spacecraft, the spacecraft would fix itself, and if that fails would safe itself and send a message to the ground to beep an on-call operator. Obviously, this type of scenario requires onboard hardware planning to reduce operations cost. In addition, standard interfaces to the PI, the POCC, the FDF, the spacecraft, etc. must be defined and adhered to. This includes developing a flexible standard language to communicate with the spacecraft.

Renaissance Operations Automation Action Team
Walt Truszkowski – 5/24/95

3.1 Health and Safety Monitoring, Anomaly Resolution

A. Description

The Flight Operations Team (FOT) determines the spacecraft's health and safety status by monitoring large amounts of telemetry and derived data and making comparisons against normative spacecraft models which either reside in the computer systems supporting the operators or in the operator's mind. For computer-based support the data/information on spacecraft status is presented in either textual and/or graphical form on subsystem display pages. Aiding the operators in this activity are visual (e.g., changing colors) and audio cues. These cues flag individual parameters failing pre-defined limit thresholds. The operators collect this data and evaluate each parameter at subsystem or system levels against some representation of a normative model.

Anomaly resolution refers to the process of reconciling observed telemetry values with expected spacecraft behavior. This process is complicated by the fact that some of the spacecraft status data changes slowly over time. In order to detect a possible anomalous situation a trend analysis function is required. A contributing factor to the complexity of trend analysis is the fact that spacecraft performance parameters are heavily dependent on orbital position and time. Spacecraft parameters change almost imperceptibly over the course of a pass. This is hard for a human to track. For example, a drastic change of 20 degrees room temperature is noticeable, a change of 20 degree over 4 hours is not. The same is true for monitoring spacecraft systems; detecting small changes in parameters is extremely difficult

B. State of Practice at GSFC

B.1 Operator Functions and Operational Systems

Health and safety monitoring and anomaly resolution are two major aspects of on-line operations in current mission operations centers. On-line operations is responsible for spacecraft command and control activities conducted during a pass. Flight supervisors, controllers, and analysts carry out plans and schedules developed to support pass operations. Execution of these activities occurs during one of three phases: pre-pass, pass, and post-pass. During all three phases spacecraft monitoring and anomaly resolution activities occur. All members of the on-line operations team participate in each of the phases.

During the pre-pass phase personnel verify the control center's readiness for supporting the up-coming pass. Command and telemetry links with the network are established and verified. Personnel verify that the control center can receive, decommutate, and display engineering telemetry. As a team, the on-line segment reviews the expected state of the spacecraft at Acquisition of Signal (AOS) and any activities planned for the support. If On Board Computer (OBC) loading

activities are anticipated, the availability of the loads is confirmed. Once these activities are complete, the control center is ready for the pass.

AOS marks the start of a pass. During the pass, engineering telemetry is monitored to verify the health and status of the spacecraft. Payload acquisition activities occur simultaneously. These activities may be real-time instrument data collection or tape recorded data playback. Required commands (if any) are sent to the spacecraft, and spacecraft tracking data is collected. These activities occur until Loss of Signal (LOS).

The Role of Operators in Performing Control Center Functions

	Controller	Analyst	Flight Supervisor	Engineer	Scheduler
Activity List Generation			Supports	Supports	Lead
Conflict Identification			Supports	Supports	Lead
Conflict Resolution			Supports	Supports	Lead
Accounting			Supports	Supports	Lead
Resource Database Maintenance				Uses	Lead
Constraint Management			Supports	Supports	Lead
T&DA Interface	Supports		Supports		Lead
Command Management					
Detailed Command List Generation	Uses	Uses	Uses		Lead
OBC Load Generation		Uses	Uses	Uses	Lead
OBC Memory Image Maintenance		Uses	Uses	Uses	Lead
Flight Software Development				Supports	Lead
Command Validation					Lead
Operations					
Telemetry Receiving	Lead		Supports		
Telemetry Recording	Lead		Supports		
Spacecraft Health Monitoring		Supports	RT Lead	Lead	
Spacecraft & Ground System Commanding	Supports	Supports	Leads	Supports	
OBC Memory Loading	Supports	Supports	Leads	Supports	
Command Verification	Supports	Supports	Leads		
OBC Load Verification	Supports	Supports	Leads		
Onboard Resource Management		Supports	Supports	Lead	
Anomaly Resolution	Supports	Supports	Supports	Lead	Supports
Contingency Planning	Supports	Supports	Supports	Lead	Supports
Simulation and Test					
Compatibility Testing	Supports	Supports	Supports	Lead	Supports
Mission Readiness Testing	Supports	Supports	Supports	Lead	Supports
Training	Supports	Supports	Supports	Lead	Supports
Mission Profile Generation	Supports	Supports	Supports	Lead	Supports
Trends Analysis	Supports	Supports	Supports	Lead	Supports
Operations Rehearsals	Supports	Supports	Supports	Lead	Supports

Post-pass activities include the following:

- **Reviewing the highlights of the pass**
- **Recording pass activities, ground equipment status, and spacecraft status in the operations log**
- **Analyzing archived telemetry to uncover subtle spacecraft problems undetected during the pass.**

A controller's primary responsibility is configuring and monitoring the ground data network. Controllers are most active during the pre-pass period. Activities during this phase include: participating in the pre-pass briefing, initializing the ground system for the pass, testing data flows, and checking command links. During the pass, controllers monitor data quality statistics, issue any required ground configuration commands, and assist the flight supervisor in spacecraft commanding activities. During the post-pass phase controllers conduct any required data operations. These activities include data playbacks and processing in preparation for analysis. Minimum skill requirements for a controller are an A.A. degree or technical training and 2 years experience.

An analyst performs short-term analysis of one or more spacecraft subsystems. During the pre-pass phase, an analyst's activities are limited. Typically, these activities include reviewing the schedule and consulting with the flight supervisor about anticipated pass activities. During the pass, an analyst performs quicklook analysis of subsystem parameters, ensuring that the subsystem is operating as expected. Post-pass activity centers on analysis of previous orbit data. An analyst position requires a B.S. degree in a hard science or technical training and 5 years experience.

The flight supervisor, technical lead for an operations crew, has detailed knowledge of both ground and flight systems. During pre-pass, the flight supervisor assists controllers with pre-pass verification of the ground system configuration. During this phase a flight supervisor reviews the schedule. On the basis of this review, the flight supervisor prepares and delivers a briefing describing planned pass activities. During the pass, with analyst assistance, the flight supervisor verifies the correct operation of the spacecraft's subsystems. If the schedule calls for real-time commanding activity, the flight supervisor ensures their transmission and verification. During the post-pass phase, flight supervisors report pass activities and plan for the next operation. Flight supervisors are usually experienced analysts and controllers. Minimum requirements for a flight supervisor are: a B.A. degree and 5 or more years of related experience, or, technical training and 8 years experience.

To support health and safety monitoring and anomaly resolution various innovations in the computer systems that support the operations team have been made. These include:

- **the use of highly graphical displays to help the operator more readily visualize the status of the spacecraft from behavioral and attitude/orbit perspectives**

Examples of such systems include the CLEAR system used for COBE, Spaceviews, and GenSAA-generated expert systems.

- the use of expert systems to augment the monitoring of telemetry data against preset limits, the detection of out-of-limits situations, the notification to operators of such occurrences, and the recommendation of corrective actions that might be taken to alleviate the condition.

  Examples include CLEAR, and GenSAA-generated expert systems.

- the capture and processing of extended duration satellite data and the generation of statistical and graphical representations of this date for use by analysts in the identification of trends.

  Examples include the Generic Trending and Analysis System (GTAS).

B.2 Planned Systems

Future approaches to health and safety monitoring and anomaly resolution activities will be significantly different from current practices. In the near-term we can expect an expanded use of expert system technology in support of routine data monitoring, anomaly detection, and recommended corrective actions. The expanded use of such systems as GenSAA, G2, SCL, etc. will help integrate more autonomous activities into the daily routine of mission operations.

The introduction of systems like GENIE will demonstrate the feasibility of totally automating pass operations. Other system concepts like the Intelligent Control Center (ICC) will also support enhanced automation to current mission operations functions.

Systems like the TRENDS system will be used to provide model-based approaches to trend analysis activities. TRENDS will provide a value-added capability to the current GTAS system. The first instance of the TRENDS system will be BASS (Battery Analysis Support System). BASS will demonstrate the feasibility of incorporating model-based reasoning as part of an automated trending system.

B.3 Possible Systems

The future of mission operations promises to be revolutionary. The trend is towards smaller and cheaper missions. The spacecrafts involved in future mission models will become a more autonomous node in the mission operations infrastructure spanning both ground and space operations. Because of this development, the very nature of ground-based mission operations will be significantly affected. The full extent of the impact to the ground and space segments is still to be determined.

Some future directions seem certain. Current centralized mission operations will be replaced with a more rigorous distributed operations concept. Teams of operators and analysts will be configured on an as-needed basis, replacing the

current practice of assembling and maintaining a fixed team for each mission. The real-time assemblage of personnel to handle critical spacecraft anomalies will require, among other developments, that advanced approaches to data and information visualization be developed and deployed. The current virtual environments work which couples virtual reality techniques and advance data visualization techniques will play a significant role future distributed mission operations. Systems like the thermal model visualization system being developed for the University of California Berkeley will provide the level and type of data/information visualization that will be useful in status monitoring and anomaly detection in such a distributed systems approach to mission operations.

To support the higher levels of automation required of future mission operations systems, goal-based approaches to automation will be heavily utilized. The current research on agent technology (AGENTS) will eventually provide the capability of realizing goal-based autonomous activities both in space, on the spacecraft, and on the ground. In the current context of the AGENTS work an agent is an autonomous process which is capable of goal-directed activity. An agent model designed to provide the type and scope of future mission operations automation envisioned is under development. The current AGENTS model identifies three major classes of agents: User Interface Agents (IA), Agent Managers, and Domain Specialist Agents. The UIA has the direct and very important responsibility of providing, to the user, access to the capabilities of the agent-based system. Additionally, the UIA is responsible for making responses available to the user in a user-customized fashion. Critical aspects of the work on the UIA are in the areas of user modeling and user interface adaptation. The Agent Manager coordinates the allocation of user expressed goals to Domain Specialist Agents and is responsible for the management of the outputs of the Domain Specialist Agents in the preparation of a response to the user and the communication of those results to the UIA. The Domain Specialist Agents use their specific domain expertise to carry out the detailed activities needed to help realize the user's goal. The cooperative activity of agents fro these three classes of agents will provide the levels of autonomy that future mission operations will demand.

The current MOCA, System 2000, etc. studies are significantly shaping the concepts for future mission operations. The traditional roles of the ground and space segments in mission operations, as currently understood, are being technologically and economically challenged. New visions for automated mission operations are emerging which will significantly revolutionize the way mission operations is accomplished. These visions include concepts such as:

- **smarter spacecraft capable of on-board fault detection, isolation and repair activities,**
- **closed loop control by autonomous systems**
- **on-board smart instrument control**
- **ground management by exception only**
- **peer-to-peer operations with space and ground components as symbiotic partners,**
- **smart real-time distributed access to mission resources**

Continued study and analysis of these system definition activities are mandatory for a focused program of automation for mission operations.

E. Recommendations

Specific - Ground Operations

1. Consider the spacecraft as a major component in future automated mission operations. Automate the spacecraft as much as possible. Have a firm grip on the impact of spacecraft automation on the ground segment of mission operations. Be prepared to make firm recommendations for spacecraft design and automation based on a detailed analysis of impacts on ground operations.

2. Actively involve the FOT as part of the design, development and review processes.

3. Support distributed approaches to mission operations.

4. Support the "operations-by-exception" paradigm when involving human operators into the control loop.

General

1. For a comprehensive automation activity start from scratch. Rethink the entire space/ground operational scenarios with the objective of utilizing automation to the fullest extent. Don't base a major automation activity on retrofitting automated components into an already existing structure.

2. Consider the intelligent hybrid systems approach for automated mission automation rather than approaches that rely on the use of a single technology. Different functions may better utilize different technologies in realizing a desired level of automation.

3. Utilize COTS and GOTS tools/components as much as possible but don't compromise on needed functionality.

4. Make the automated systems easy to use. Pay particular attention to usability issues. Integrate a full range of user interface/interaction modalities into the automated systems.

5. Make use of innovative technology testbeds as part of the evaluation process for new automation initiatives.

3.2 Flight Operations - Command and Control

A. Description

This operations category involves the real-time control of spacecraft and ground resources by Flight Operations Team (FOT) members and supporting software. These activities are performed in a Mission Operations Center (MOC) and typically involve considerable interaction between the FOT and the ground data system. The FOT uses operator interface software in the ground data system to send commands to the spacecraft during a real-time contact called a pass.

B. State of the Practice at GSFC

B.1 Operator Functions and Operational Systems

In a typical GSFC operations control center, the activities of the Flight Operations Team (FOT) for a real-time contact with a spacecraft are divided into three phases: pre-pass, on-pass, and post-pass. During the pre-pass phase, the FOT typically configures ground equipment and verifies that equipment and network links are ready for the contact.

During the on-pass phase, the FOT sends commands to the spacecraft to perform scheduled activities, such as dumping and uploading tables and managing on-board memory resouces. Activities are performed as defined in a pass plan, and are subject to specified preconditions and time constraints. Some data exchanges during the contact may take place automatically at pre-determined times, under the control of the spacecraft's onboard computer and active command load. Other activities during the pass are initiated by the FOT. For FOT-initiated actions, the FOT must verify that required preconditions and time constraints are satisifed before sending the command, and must verify that the command was properly sent and the desired action was performed. Problems such as poor quality data transmission may require that some activities be repeated or rescheduled.

During the post-pass phase, the FOT performs operations accounting and file management activities to summarize the results of the contact and to prepare for off-line analysis of data recorded during the contact.

The FOT sends real-time commands using a Spacecraft Test and Operations Language (STOL). TPOCC-based missions use the TPOCC STOL (TSTOL). STOL statements, called directives, can assign and test values of system variables, and cause commands to be sent to the spacecraft. Access control privileges are used to ensure that commands are only sent by authorized operations personnel. Command verification software checks commands before they are transmitted to the spacecraft.

The FOT can enter directives individually, or include them in STOL procedures. STOL procedures are often used because they can test preconditions, set system variable values, send one or more commands, and perform command verification tests together in one predefined sequence. Arguments can be passed to STOL procedures when they are executed. STOL procedures are the highest level of automation currently used in GSFC control centers.

B.2 Planned Systems

a. Genie – Code 520 is currently developing the Generic Inferential Executor (Genie), a tool that allows pass automation applications to be easily constructed. Genie is built on GenSAA, and will initially operate in TPOCC control center environments. The first demonstration application of Genie is to automate routine pass operations for the SAMPEX mission. The demonstration is planned for spring 1995.

With Genie, the FOT can build a pass script which defines the monitoring and commanding tasks that are to be performed during a pass. Tasks are arranged in flowchart-like structures that allow the specification of sequential and parallel activities. Parameters are defined for each task to indicate the time window during which it can be executed, its expected duration, and the number of times it can be automatically retried. Expert system rules are used to define the preconditions, normal actions, post-conditions, and failure actions that are associated with each task. Rules are also used to define periodic or continuous monitoring tasks that must be performed during various intervals of the pass.

A graphical workbench allows the user to build pass script templates which encode the tasks necessary to mimic the FOT interactions with the spacecraft during a pass. These templates are then configured by a mission planner with data specific to a particular pass. The script is loaded into the Genie runtime system during pre-pass preparations and executed. A graphical status and control display tracks progress during the pass. If non-nominal conditions occur, the FOT is notified; otherwise, the tasks are fully automated.

b. EOS Ground Scripts – The Flight Operations Segment (FOS) of the EOSDIS Core System (ECS) is being designed to include the capability to partially automate routine command and control operations by using a "ground script". This approach is an extension of the ground script approach used by NOAA.

B.3. Possible Systems

The following operations automation capabilities are being considered or studied that may eliminate some command and control functions that are currently perfomed manually.

a. Applications of Genie – Several missions are considering the use of Genie to automate pass operations. SAMPEX may use Genie operationally after it is demonstrated. SWAS pass operations are very similar to SAMPEX, and could be autotated relatively easily by modifying the SAMPEX pass script.   SOHO has

expressed interest in using Genie, especially if pass scripts can be generated automatically based on the output of its planning system. ACE operations are relatively straight-forward, and could be easily automated with a Genie pass script.

b. Intelligent Command and Control (ICC) Project – Code 513 is conducting an RTOP project called the Intelligent Command and Control System for NASA. The project has the following objectives: 1) Demonstrate that spacecraft command and control can be improved and simplified by building and operating a real-time, intelligent, object oriented command and control system that uses animated graphical user interfaces; 2) Create a command and control system that can act as a cooperative member of the FOT; 3) Demonstrate that MOC command and control functions can be fully automated and perform intelligent machine-based decision making; 4) Demonstrate that such a system would show significant cost savings by reducing FOT staffing and reducing operator errors.

The project is developing a prototype ICC that will be demonstated in a side-by-side comparison with existing command and control capabilities. Project team members include the University of Illinois at Urbana-Champaign, and the Geogia Institute of Technology. The Univ. of Illinois has developed several prototype components and demonstrated them at GSFC for a simulated SAMPEX pass: ISAM (Intelligent Support for Activity Management), CoSMO (Cooperative Support for Mission Operations), and ASPIRE (Automated System Prototype & ISAM Reasoning Extensions). Several other components of the research are underway.

The project is targeting an ICC technology readiness date of no earlier than FY '99. Portions of the technology developed may possibly be spun off into operational capabilities before then.

c. Virtual Mission Operations Center (VMOC) – Code 520 is conducting a research project that is defining concepts and developing prototypes for the Virtual Mission Operations Center. Part of this effort is examining the automation of command and control activities. The VMOC will provide tools to assist operations personnel with routine activities, including graphical assistance in building and editing pass plans. A COTS product, the Intelligent Mission Toolkit (IMT) from Storm Integration, Inc., is being used to evaluate approaches for this automation goal. The VMOC will also include workgroup computing tools such as integrated email, shared databases, video conferencing, and shared blackboards. The results of this research may be applied in future GSFC MOCs.

C. State of the Practice at Other Organizations Relevant to GSFC

a. NOAA – NOAA operates its constellation of weather satellites from its operations center in Suitland, MD. Several of the NOAA-x series are operated from a single set of command and control stations that are monitored by 1-3 operators. Command and control operations during spacecraft contacts are nearly completely automated for routine operations using "ground scripts".

Ground scripts are comprised of STOL-like directives with timetags. Essentially the same ground script is used for every contact, and for every satellite. This is possible because the satellites are nearly identical, and routine operations are fairly simple and the same for every contact. The ground data system was custom developed several years ago by Loral.

b. NRL – The Naval Research Lab operates its constellation of research satellites from its operations center at Blossom Point. Routine operations are highly automated, with very little operator intervention required. Displays that depict the status of operations are highly graphical. The ground data system software is based on the the COTS product OS/Comet, developed by Software Technology, Inc.

c. JPL – JPL has recently completed a study of their potential use of the Spacecraft Command Language (SCL), a product of Interface & Control Systems, Inc. (ICS). SCL is a reusable language for spacecraft command and control that can simplify ground and flight development and operations. JPL is considering the use of SCL on future JPL missions. Most previous JPL projects have developed custom languages for onboard sequencing, requiring significant changes in ground support software for each mission. JPL is interested in adopting a standard onboard sequencing language that would not change from mission to mission.

SCL is intended for use both as a ground command and control language and as on on-board sequencing language. It has both procedural and rule-based elements. For ground applications, SCL can be used to increase command and control automation.

In the report "Spacecraft Commnd Language (SCL) Study Report", October 26, 1994, by J.A. Rohr, et. al., JPL concluded that SCL is a primary candidate for use in future JPL missions. The report recommends that SCL and one other language (probably PRS from SRI International) be used in two prototypes of mission operations environments for a future mission. The report also recommends that other candidate languages be identified and evaluated.

D. Issues

For command and control, and all operations automation areas, Code 500 needs to closely examine what is being done elsewhere.

– We may not have been sufficiently aggressive in applying known technology to automate our operations.

– We should seriously consider adopting approaches and tools that are being successfully used elsewhere.

E. Recommendations

Specific – Command and Control

1. Automate routine command and control – The goal for 2nd generation Renaissance MOCs should be to automate all routine real-time command and control operations. Automation software should perform command and control operations according to an operations script that is based on a pass plan. Command and control automation software should recognize anomalies during the pass and either attempt to recover, if the procedure for handling the anomaly is defined in the script, or else call for FOT assistance. (Benefit = High)

2. Interface to planning and scheduling system – The command and control automation software should interface with the planning and scheduling software in the MOC to receive the pass plan. No FOT intervention should be required to define the automated operations script for routine passes. (Benefit = High)

3. Improved communication – Strengthen the communication between command and control automation efforts that are underway in Code 500. Improve awareness of command and control automation successes in related organizations. (Benefit = Medium)

General

1. FOT involvement – Ensure that command and control automation efforts involve the active participation of FOT members.

2. Consider both COTS and GOTS – Implement operations automation capabilites with COTS and GOTS tools, rather that with custom development, whenever operations automation objectives can be satisfied adequately in this way. When selecting software to support command and control automation, consider both commercial products (COTS) and government-developed building blocks (GOTS).

3. Look outside – Develop and maintain an awareness of automation practices at relevant organizations outside GSFC and NASA.

Renaissance Operations Automation Action Team
Jamie Koppersmith – 6/6/95

4. Orbit and Attitude Operations

4.1 Orbit Determination Daily Support

A. Description

Orbit determination support is provided for more than 15 spacecraft. The support is anywhere from daily to once a month with a process that is automated to a large degree. The process begins with the retrieval of the most recent atmospheric density information and predictions. The solar flux values provided by the National Oceanographic and Atmospheric Association (NOAA) enable the FDF to calculate the atmospheric density. This data is downloaded from the NOAA computers via FTP. Only the solar flux files are retrieved, the force model is defined and the orbit determination (OD) process can begin. The Tracking & Data Relay Spacecraft (TDRS) and user spacecraft tracking measurements are collected autonomously throughout the day by the Data Collection and Data Retrieval System (DCDR). The TDRS OD is done first. Once the TDRS orbits are determined and stored into Permanent TDRS Orbit Files (PTOFs), they are held fixed and the user spacecraft orbit determination is performed. The daily production is run by the Orbit Production Automation System (OPAS). This software creates and initializes the files for each day's required jobs. OPAS calls the Goddard Trajectory Determination System (GTDS) to perform the actual batch OD. Automated Quality Assurance is done using the QATool software. This software compares extracted values from the output files against predetermined tolerances. The QATool creates a report that will flag any values that did not pass the criteria. The information is passed back into OPAS and the user decides whether to override a failed job or investigate the anomaly.

B. State of the Practice at GSFC

B.1 Operator Functions and Operational Systems

The daily OD support begins with the downloading of the solar flux data from NOAA. This data is FTPed and then converted and formatted automatically for use in GTDS. OPAS is then run to create the necessary files for the day's jobs. The operator then initiates the TDRS OD. After confirming that the jobs passed the QATool checks, the initiator then initiates the user spacecraft OD. The operator again confirms that the jobs passed the QATool checks, then initiates the deliver sequence which sends out or promotes the various products. The DCDR system is almost completely automated although the database requires maintenance every 5 to 7 days.

The following operational systems are used:

a. Data Collection and Data Retrieval - This is a collection of programs that automatically processes and formats tracking measurements received over the NASCOM lines. Database maintenance is required every 5 to 7 days.

b. Orbit Production Automation System - This software schedules the required jobs, creates the necessary files, and submits the OD runs while acting as a high level executive over the other orbit utilities.

c. Goddard Trajectory Determination System - This software performs the batch differential correction orbit determination and creates the solution states and ephemerides.

d. QATool - This software compares extracted values from any text file, created by any program, against user determined tolerances. It creates a report that can easily identify failed values.

e. Other orbit utilities - There are many other utility programs that are used to create specific products for various missions. Most of these utilities simply reformat the information from GTDS or transform the information into another frame of reference.

B.2 Planned Systems

The FDD is currently writing specifications for a modularized single system that would perform all of the above tasks, or only the tasks required for the mission, when integrated.

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4.2 Acquisition Data and Orbit-Dependent Product Generation

A. Description

The acquisition data process uses the spacecraft ephemeris to predict how ground station and TDRS antennas should point to establish contact with the spacecraft. The data can be created by using an automated system or a real-time system. The output of these programs is sent to the ground station by user command. A number of programs also ingest the spacecraft ephemeris to predict ground station coverage, TDRS coverage, sunlight entry and exit times, beta angles, etc. These programs must be initiated by the user.

B. State of the Practice at GSFC

B.1 Operator Functions and Operational Systems

Operators must initiate the programs to produce the acquisition data. They also must initiate any of the prediction programs. The output of the acquisition data or the prediction programs is quality assured by hand and then sent to its final destination by user command.

The following operational systems are used:

a. Acquisition Data Subsystem (ADSS) - This system is not automated but a group of CLISTs on the mainframe automatically perform the setup of the namelists and initiation files.

b. Acquisition Data Generation (ADG) - This is a program that performs real-time acquisition data generation.

c. PSATGN - This program computes orbit-based events such as sunlight entry/exit times, apogees and perigees, etc.

d. TDRS Operations Planning and Scheduling Aids System (TOPSAS) - Predecessor to PSATGN.

e. Zeta-Beta Generator (ZEBEGEN) - Compute sun angle parameters: zeta and beta angles.

f. Mission Planning and Scheduling System (MPSS) - Computes orbit-based events.

B.2 Planned Systems

a. Portable Acquisition Data System (PADS) - This is a program that is designed to be run by user control centers and the Network Control Center (NCC).

4.3 Attitude Support and Attitude-Dependent Product Generation

A. Description

Attitude operations can generally be divided into two categories: product generation and attitude support. The first is involved with producing predictions for high-gain antenna contacts and angles, available guide stars, and predictions for attitude sensor coverages. All the programs must be initiated by a Flight Dynamics user and the output then is usually sent to the Command Management Facility (CMF) by the user. For the attitude support, it involves performing attitude determination and monitoring the attitude control system. It also often involves special types of analysis that rely upon results of the attitude determination process. The necessary telemetry for the calculations and monitoring is either sent as a real-time stream or is sent as post-pass files. For monitoring recent spacecraft missions, Flight Dynamics has been using GenSAA-based systems to view the real-time telemetry or X-Window displays straight from the POCCs or MOCs. Either way, the user must initiate the program. For older missions, the monitoring is usually performed using institutional software which unpacks the telemetry and displays it. Set in motion by the user, the attitude determination program usually requires a certain level of interaction with the user.

B. State of the Practice at GSFC

B.1 Operator Functions and Operational Systems

On the FOT side, operators must either enable the real-time telemetry to flow or they must send over the telemetry files after the pass. Additionally, the FDF does not usually receive all the telemetry, some of it is stripped out by the FOT during their level-zero processing. FDF usually does not have to do anything to get the telemetry. Once it is in the FDF system, the user must initiate the attitude determination process and often interact with it. For GenSAA or X-Windows displays, FDF personnel usually must log onto a server or an actual MOC or POCC system to get the data or screens that we desire. For the older missions, the telemetry can be viewed as the first step in the attitude determination process which requires logging onto the FDF mainframe.

The following operational systems are used:

The systems below usually require user interaction but FDF personnel are working towards getting them to run sequentially in a batch mode.

a. Telemetry Processor (TP) - This is the front end of the Attitude Determination System (ADS) that unpacks the data and writes it to an Engineering Data Set (EDS), which is a file containing all the required attitude sensor values necessary for attitude determination. It can either be a file or a set of files.

b. Data Adjuster - This is the portion of the ADS that ingests the EDS and applies various misalignments and biases thereby producing the Processed Engineering Data Set (PEDS).

c. Coarse and Fine Attitude Determination System (CFADS) - This portion of the system computes the spacecraft attitude using the PEDS. It also computes certain biases such as the gyro bias or the magnetometer bias. Instrumental in solving for attitudes with star tracker telemetry is the star identification portion of CFADS.

d. Quaternion Estimation Attitude Determination Subsystem (QUADS) - This is a subsystem of the ADS which uses a different algorithm to compute the spacecraft attitude, however, it is not usually used for nominal routine operations.

e. There are many other programs which perform calibration, ephemeris comparisons, star identification, sensor contacts, and a number of other functions. They are listed below:

1) Definitive Attitude Determination
2) OBC Attitude Validation
3) FEFCAL - Fixed-Head Star Tracker / Earth Sensor /Fine Sun Sensor Calibration
4) IRU Calibration - Inertial Reference Unit Calibration
5) TAM (Three-Axis Magnetometer) Misalignment/ Bias Determination
6) FSS (Fine Sun Sensor) FOV (Field of View)
7) SSPP Calibration
8) Attitude Prediction
9) High-Gain Antenna Contact Prediction
10) Guide Star selection
11) Sensor Occultation Predictions
12) OBC Orbit Validation
13) Delivery Formatting
14) Transmission
15) Ephemeris Compares
16) Uplink Table Generation (UPTAB)

B.2 Planned Systems

a. GSS - Generalized Support System - This is a modular generalized attitude determination system that essentially incorporate all the functions of the programs listed above. It should lend itself to a certain degree of automation.

b. UIX - This is a user interface being developed by FDF that will allow a certain degree of automation to be utilized when running all the above programs. It probably will allow sequences to be created whereby modules can be run one after another without user interaction.

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4.4 Sensor and Actuator Calibration

A. Description

Sensor calibration is a process that compensates measurement information for misalignments and instrument anomalies and involves human analysts to interpret calibration results and to trend calibration parameters over time. It usually involves a significant amount of data to be collected and processed. Calibrations for certain sensors, such as gyros, require the spacecraft to perform prescribed maneuvers to isolate axial specific pieces of data. The only actuators that are calibrated are the thrusters used for orbit-adjusts.

B. State of the Practice at GSFC

B.1 Operator Functions and Operational Systems

Sensor calibration is normally conducted off-line. An FDF analyst must collect large batches of data so runs can be made to minimize the random error sources and isolate the systematic ones that can then be calibrated. The analyst usually runs the attitude determination system and then the calibration routines. There is definitely room for automation but the process often requires human judgment. As for real-time calibration, the only thing that is presently solved for is the gyro bias. There are future plans to incorporate a Kalman filter to ascertain misalignments. For thruster calibration, the actual orbit adjust burn is compared to the one predicted by the FDF planning process. A number of iterations are made to isolate the thrust-scale factors. These are the means by which the next burn can be calibrated. This process involves significant human interaction though AMPT, which is described elsewhere, could supplant much of the interaction with interactive automation.

The following operational systems are used:

a. ADS & CFADS - As noted previously, these programs often require human initiation or intervention but can often be streamlined to run in batch.

b. Fixed-head star tracker (FSHT)/Earth sensor assembly (ESA)/fine Sun sensor (FSS) calibration utility (FEFCAL)

c. Inertial reference unit (IRU) calibration (IRUCAL) utility

d. FSS Field of View (FOV) utility (FSSFOV)

e. Three-axis magnetometer (TAM) calibration (TAMCAL) utility

f. GMAN
g. GTDS

Renaissance Operations Automation Action Team
Jamie Koppersmith – 6/6/95

4.5 Orbit Maneuver Support

A. Description

At present, the planning of orbit maneuvers can be a very time consuming process. Flight Dynamics personnel must resolve conflicting spacecraft and orbital constraints to arrive at a maneuver plan that will achieve the desired change in orbit while keeping the spacecraft safe. The process begins with the knowledge of how much energy must be added to the spacecraft's orbit. The maneuver analyst uses a Flight Dynamics generated ephemeris to run a program called ACQSCAN which lists the apogees, perigees, station coverage, and shadow constraints. When the proper time of maneuver is determined, the General Maneuver Program (GMAN) is enabled to determine the end-state vector at the end of the orbit adjust burn. A predicted ephemeris is propagated based upon these end-state vectors and predictive products such as station and sensor coverages are computed.

B. State of the Practice at GSFC

B.1 Operator Functions and Operational Systems

Human interaction is required at most stages of the maneuver planning process. At present, the resolution of the conflicting constraints and requirements is completely performed by FDF personnel. Also, the initiation of the programs to propagate the ephemeris, check perigees, apogees, and station coverage, and model the orbit adjust burn are all initiated by a person.

The following operational systems are used:

a. Goddard Trajectory Determination System (GTDS) - As stated previously, this piece of software computes orbits from tracking information and also propagates orbits from an initial vector.

b. ACQSCAN - This program computes perigees, apogees, station coverages, and shadow times for a spacecraft. It must be set up by a person and rerun when the orbit changes.

c. General Maneuver Program (GMAN) - This piece of software models the burn and outputs and an orbit vector based upon that modeling. It also takes some constraints into account when modeling the burn. It must be set up by a person. Frequently, this program is iterated in the quest to balance all constraints and requirements.

B.2 Planned Systems

A system is created at this time to integrate all the steps of maneuver planning into one holistic approach. This system is called the Automated Maneuver Planning Tool (AMPT) and it will incorporate fuzzy logic to resolve all the planning constraints and requirements. Essentially, it captures the analytical thinking that is used by FDF personnel to hone in on the correct solution. All the recursive runs are performed by the software instead of a person. This system has been prototyped and has reduced hours of intensive human effort down to several minutes of machine iterations to converge on the maneuver plan that will work and will satisfy all definable constraints and requirements.

Renaissance Operations Automation Action Team
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Recommendations for Section 4

As evidenced from the above sections, there are a number of efforts under way to automate various aspects of Flight Dynamics support. Over the coming years, automation will become instrumental in the quest to rein in operations costs but to realize automation's promise, ingenuity will be necessary. Whereas , in the past and present, orbit and attitude operations were concentrated in the Flight Dynamics Facility, in the future, they will be scattered amongst the many control centers and ground sites involved in NASA missions. The challenge will be to get the different pieces of software functioning automatically while taking into account the disparate physical residences that host the host software. Based upon the above sections, the below recommendations might prove helpful.

1. Continue with the efforts to automate the individual software packages that deal with orbit determination, acquisition data generation, attitude support, product generation, and maneuver support.

2. Flight Dynamics has been looking into moving more of the orbit determination and even the maneuver planning onto the spacecraft. These efforts should continue and be intensified.

3. Flight Dynamics has also initiated efforts to distribute FDF functions to control centers and tracking stations. In the future, many of the "products" will be created on FDF-defined software, be they FDF produced or COTS, but run by the people who need information, not a central facility. These efforts should also continue and be further intensified.

5. Data Collection, Processing, and Distribution Operations

A. Description

This operations category involves the real-time capture, level-zero processing, and distribution of scientific, housekeeping, and engineering spacecraft data to investigators as well as those involved in spacecraft orbit and attitude determination. Distribution of data may be either in real-time, in 'quick-look' which means one processed pass at a time, or as full level zero data sets which include 24 hours of data.

B. State of the Practice at GSFC

B.1 Operator Functions and Operational Systems

There are two systems at GSFC which represent the most current state of the practice in this area. The first system, the Sensor Data Processing Facility (SDPF) was built within Code 560, and provides Data Capture and Level Zero Processing and Distribution functions. It includes three independently operated subsystems: the Packet Processor II Data Capture Facility (Pacor II DCF) which captures the data and performs Level Zero Processing, the Generic Block Recording Subsystem (GBRS), which records NASCOM blocks as they enter the building for redundancy to expedite fault recovery, and the Data Distribution Facility (DDF) which distributes processed data. The SDPF is planned to support the Submillimeter Wave Astronomy Satellite (SWAS), the Solar and Heliospheric Observatory (SOHO), the X-Ray Timing Explorer (XTE), Hubble Space Telescope (HST) in 1995, and other missions thereafter.

The second system, the Fast Auroral Snapshot Explorer Packet Processing System (FAST PPS) was built within Code 520, and also provides Data Capture and Level Zero Processing and Distribution functions. It is based upon two integrated subsystems: the VLSI-based data processing hardware, and the Telemetry Processing Control Environment (TPCE). In addition to supporting the FAST mission in 1995, these components have also been used for the EOS AM I&T system, the Wallops Orbital Tracking Station (WOTS) Front End Processor, and the ACE I&T system.

The following sections provide detailed information about the operator functions and level of automation provided by these systems.

B.1.1 Sensor Data Processing Facility (SDPF)

The SDPF consists of three systems mentioned above: GBRS, Pacor II, and DDF. The primary system, Pacor II consists of five subsystems: Pacor Matrix Switch (PMSS), Pacor Information and Control (PICS), Front End (FES), Realtime

Output (RTOS), Production Data Processor (PDPS), and the Quality Analysis Workstation (QAWS).

Pacor II is a schedule-driven system. The functions performed by Pacor are: block and frame processing, packet reassembly, routine product generation, special request products and quicklook generation, quality and data accounting information, and storage and forwarding of prepared datasets to the DDF or directly to the investigator.

Scheduling - Spacecraft contact schedules are transmitted daily to Pacor by NCC for TDRSS missions and by the RUST terminal for Ground and Deep Space Network missions. Schedules are verified manually to assure that all were received.

Data Capture - Realtime and/or playback acquisitions are set up five minutes prior to acquisition of signal (AOS) start time. If the session(s) do not set up, the problem is resolved prior to acquisition of signal.

Realtime/Playback acquisitions are monitored for assurance that all data are received and processed. Data dropouts, excessive CRC's or Reed-Solomon errors, and other data anomalies that occur in Pacor II are verified as valid by checking with the GBRS and/or the mission FOT.

Once all data are received, an acquisition is terminated automatically by the system. If the realtime and/or playback acquisitions do not terminate, the analyst will manually terminate the acquisition. If the session(s) do not terminate, fault isolation and resolution begins.

For redundancy and back-up, data is also captured and saved on the GBRS system.

Realtime Data Delivery - Realtime data delivery is scheduled by analysts according to user specifications. Users request all, none, specific passes, or certain virtual channel and application ID pairs.

Realtime output sessions set up automatically five minutes prior to AOS. If the realtime sessions do not set up, fault isolation is initiated by the analyst while the system continues to attempt connection. Once connected, RTOS sessions are monitored manually for user/Pacor connectivity. After LOS, if the RTOS sessions do not terminate, fault isolation and corrective actions are initiated.

Currently, high data rates cause many Science Operations Center (SOC) systems to go down. These systems are unable to ingest data at high rates.

Products - All data that have a product specification in the system are sent to the PDPS. The first step of production is automatic or manual pre-product assessment. If the data passes pre-product assessment, then automatic product generation will occur when a specification is complete. If data does not pass

automatic pre-product assessment, an analyst will manually assess the pre-product.

After product generation, product evaluation occurs via automation and/or manually. If a product fails evaluation, the failure is investigated by the analyst.

Subsequently, a Data Availability Notice is sent via automation to the Distribution Facility (DDF). The DDF then transmits a Data Availability Acknowledgment (DAA) to the Pacor system. The DDF is responsible for initiating product retrieval from the Pacor system and for meeting product distribution requirements of the mission investigator as defined in the Interface Control Document (ICD).

Non-Routine Products - A non-routine product may be high priority and require generation immediately after a phone request is received from a mission investigator. Data time periods available for the non-routine product are from the beginning of the Mission to the current day.

Data Distribution -
[*Need to discuss DDF here - how automated is it?*]

Anomalies - Schedule, Frame, Front End, Pre-product, Product, Product QA, and RTOS are data dumps. Along with the Front-End Tool, they are used by the analyst for evaluation and fault-isolation analysis. The QAW dumps are used by the analysts to verify and fault isolate block, frame, and packet errors.

Reports - An Event Anomaly Report is prepared manually to document information for investigation and/or resolution during all scheduled support between NASCOM, the Ground Station, JPL, and Pacor. Anomaly reports are a tracking device for late data acquisition, no data during a scheduled pass, equipment/line problems at the station or JPL causing non-recoverable data loss or corrupted data.

A Daily Status Report is generated manually for each satellite at the end of the Julian day (24:00 Z). These reports are distributed daily to NASA management and the Project. These reports are planned to be generated by Oracle Forms.

Current System Bugs - The Pacor II system was designed to require minimal analyst support of one analyst per mission for each shift. Once the system is fully developed to its planned potential, the above will be implemented. The majority of problems are due to the PDPS. After the PDPS problems are fixed, the Pacor II analysts will have minimal difficulties with the system. Currently, planning an Expert System for anomaly detection and resolution is on hold until the hardware and software function as originally planned.

Staffing - [*Need to discuss staffing of SDPF here...*]

B.1.2 Fast Auroral Snapshot Explorer Packet Processing System (FAST PPS)

The FAST PPS is a schedule driven system which captures, processes, and distributes data and quality metadata from the FAST spacecraft, either one pass at a time or as a full Level Zero Product on day boundaries. The system is highly automated, leaving the operator with minimal tasks.

Scheduling - Once per week, the operator must download the RUST schedule manually using FTP. At that time, schedules are verified manually.

Data Capture - Nominally, as data is captured in real-time, the operator does not have any functions to perform. For the FAST mission, some data arrives on tapes. In this case, the operator is required to mount tapes of recorded spacecraft data, which the system then processes and distributes the data. This occurs approximately every other day.

Unlike the SDPF / Pacor II, the system does not pause between data capture and data processing to assess data quality and decide whether to proceed. Whatever data was received will be processed, regardless of frame or packet quality indicators.

Real-Time Data Delivery - The data is automatically sent to the IGSE in real-time at every pass for the first 60 days after launch. If there is a requested change to the packet selection for real-time, this must be done manually.

Products - During nominal production of data products, the operator is not involved. No specific quality analysis is done by a human prior to data delivery. The system sets quality flags which are provided in metadata to the end-users of the data.

All data delivered to the investigators is provided one pass at a time. 24-hour datasets are also created and provided to the Flight Dynamics Facility for orbit and attitude determination.

Non-Routine Products - Because all data is provided to the investigators immediately, in 'quick-look' mode, non-routine requests are not expected.

Data Distribution - Nominal data distribution is fully automated. Communication occurs between the sending and receiving systems, and the operators are only involved if there are communication problems. The FAST PPS is able to record and hold data to be distributed for a limited amount of time in the event of a failure on the receiving end.

Anomalies - The operator is required to handle all anomalous conditions; fault detection, isolation, and recovery are not automated. These anomalous conditions may include: communications failures possibly indicated by excessive block CRC errors, and hardware failures. Beyond these, as long as the system is continuing to process data, the operator is not involved. Many data quality parameters are monitored by the system, but these are sent as flags to the end users of the data and the operators do not react to them.

Reports - Reports and event logs are generated automatically by the system.

Current System Bugs - FAST PPS is still undergoing testing. Version 4.1 was only been able to process 40% of the data without inducing errors. Thus, humans were heavily involved in the production of data. However, FAST PPS Version 4.2 was just released and resolves most of the internal problems. That release comes nearer to the 100% 'clean' data production and distribution, and 4.3 is expected to fully accomplish the goal.

Staffing - The FAST PPS is located in Building 3/14 and staffed by TPOCC operators. The prime shift is staffed with one operator (9-5, M-F), who is also responsible for controlling the TPOCC matrix switch. Nominally, the only thing which this operator does with respect to the FAST PPS is to glance at the summary screen which shows status and sequence of processing to ensure that processing is progressing and has not crashed. Data quality thresholds are not monitored.

There is also a System Administrator who works on the prime shift only and is able to assist with system problems.

B.2 Planned Systems

B.2.1 FAST PPS Enhancements

The FAST PPS's Telemetry Processing Control Environment (TPCE) is a reusable user interface and control system which is undergoing constant improvement. The internal control system has been rewritten using the CLIPS Expert System software to increase automation in the areas of fault detection, isolation, and resolution. In addition, there are plans to automate the receipt of schedules.

B.2.2 Landsat 7

The newest data capture and level zero processing system under development is the Landsat 7 Processing System (LPS).
The Landsat Processing System is co-located with the Landsat Ground System at the Land Process Distributed Active Archive Center (LP DAAC), at the Earth Resources Observation System Data Center (EDC). The LPS coordinates operations with the LGS in accordance with the Landsat 7 contact period schedules.

LPS receives the equivalent of 250 ETM+ scenes per day of wideband data from a maximum of six LGS contacts per day. In realtime, raw wideband data is stored by the LPS. Subsequently, the LPS retrieves and processes the raw wideband data, at lower than real-time rates, into Level OR , browse image, and metadata files, for later transfer to the LP DAAC.

The LPS is required to begin supporting the Landsat 7 system integration and test activities at least 12 months before launch. Once operational, the LPS will operate 24 hours a day for a minimum mission five year life.

[*How automated will it be?*]

B.2.3 Earth Observing System Data and Operations System (EDOS)

EDOS is planning automation of all data processing activities except for error exception handling with two data analysts per shift around-the-clock. It is in very early stages of design at this point, with CDR planned for 8/95.

D. Issues

D.1 Data Quality Requirements vs. Automation

In comparing the existing systems, it is evident that two distinct philosophies have been used. The first (Pacor II) is to ensure near 100% perfect data quality to the end users, which implies a more complex system and higher operations costs. The second is to increase automation, in part by reducing data quality check points. Neither of these systems are fully operational yet; but, when they become operational it will be interesting to see the user response to the lower level of data quality.

Decisions have not been made regarding data quality / reliability requirements. These requirements are not clearly stated or evaluated from a cost perspective in current DMR's.

D.2 System Reliability Limits Automation

Much of the tasks performed by operators/analysts pertain to trouble shooting, either due to verifying new software or hardware, or due to network or system problems. No matter how highly automated the system is in its design, low system reliability will cause an increase in staffing costs. The reliability of the Data Processing System itself, as well as the networks and the other systems with which it interacts is crucial to being able to reduce operations costs.

D.3 Cost of Building and Maintaining Automation

Although it is agreed that automation saves costs in terms of number of persons required to run the operational system, this savings must be evaluated with respect to the cost of building and maintaining the automated software. It is not clear that greater automation always implies lower cost.

D.4 Standardization On-Board Spacecraft

Greater standardization across missions on-board spacecraft will increase ability for reuse in ground systems, and thereby reduce their cost. Many aspects of

automation do not become cost effective until they are able to be used on multiple missions.

This is beyond the control of the ground systems developers, but if the ground system perspective were pulled into Phase A studies, impact of spacecraft design decisions to ground system costs could be considered earlier.

E. Recommendations

E.1 Cost Benefit Analysis using the SDPF vs. FAST PPS (1996)

The FAST PPS system is really a highly automated system. There are few improvements to suggest to this system. However, it remains to be seen whether the data quality will be satisfactory to the end users.

A comparative analysis of the costs of operating the FAST PPS vs. the SDPF systems should be undertaken once these systems are both in fully operational mode. Then, a comparison should be made of user satisfaction and level of work (processing) needed at the end-user site. Based on this, we will have an idea of whether to:

a - Reduce the requirements and functionality of these systems, allowing lower quality in return for simpler systems and lower operations costs

b - Attempt to fulfill the same requirements with greater automation through Expert System or other technology, promoting more complex systems in return for high data quality and also lower operations costs

E.2 Automate Handling of Predictable Anomalies

A number of problems which currently require the involvement of operators stem from network outage. Automatic fault detection, analysis, and fail-over should be in place so that recovery from this routine situation does not involve human intervention. Other routine anomalies should be similarly handled. All repetitive functions should be automated.

Systems should not be designed with the assumption that all telemetry is down linked error free. A system designed and built that has tools available for fault isolation and resolution is recommended. A library of tools designed for CCSDS telemetry analysis should be available for use as needed.

E.3 Automate Receipt of Schedules and Reporting

Both existing systems currently receive RUST schedules manually, and this is a prime candidate for automation. In addition, the level of automation of reporting could be more highly automated, along with the mechanisms for routing the reports.

E.4 Limit System Change

Although in some cases this may be an unrealistic goal, managers must realize the hidden costs of making system hardware or software changes. Not only are there testing costs, but there is increased workload to operations personnel as the new software is verified in an operational setting. Although the software may be fully automated, humans will still be pulled in to 'babysit' upon each new version.

The use of increased automation capabilities will add complication to making system changes. With increased automation capabilities, the data, system, and the automated features require fault isolation and analysis . The cost of development and maintenance of the automation must also be considered.

E.5 Nominal Activities and Expert Systems

Nominal operations activities should all be automated, and exception handling left to operators with next step suggestions from a rule-based expert system. Due to the high turnover of data analysts, an expert system is a solution for record keeping of all problems and availability of suggestions for problem resolution to an operator.

E.6 Table-driven, Generic Systems

For single mission data processing systems, such as the FAST PPS or Pacor II Globe, it is crucial that the system is not developed with user's criteria for data evaluation to remain static for the mission life. A table-driven system is necessary because data evaluation requirements criteria change.

As experienced with the GRO tape recorders, the failing recorders caused the data quality to first degenerate slowly and continue to total non-use of the recorders data since March of 1992. GRO data evaluation was done manually by checking certain data criteria, and thus caused no problems in evaluating data.

"Mission specific" software should not be the mindset. There is no such thing as "mission specific software, but rather software that was developed for a particular mission and "first used" for that mission, but thereafter is used for all missions. A generic mindset is necessary.

E.7 Computer Human Interfaces (CHI's) and Centers of Expertise (COE's)

Common CHIs should be designed for data processing systems. All operations of the system should be accessible from one terminal. Moreover, the CHIs should be layered so that as an improved capability COTS database package becomes available, a new database can replace the existing database. CHI's should not be limited to one physical area. The concept of a virtual operations center, where experts can participate on an as-needed basis, should be explored.

Centers of Expertise (COE) need to be maintained, possibly at a remote location, so that the expertise developed is never lost. Once systems are automated and do not require an analyst for the day-to-day operations, an expert system can notify

the COE for error exception handling analysis. The COE then can remotely perform fault isolation and resolution analysis.

E.8 System Design for Modularity, Flexibility, Expandability

Automated systems should be designed with expansion in mind. At the outset of a mission, repetitive functions of operators are not known. As these are discovered, the operators should have the capability to write their own scripts/macros which could be easily added to a rule-based system.

Testing tools developed should be used for fault isolation while a mission is operational. These tools should not be discarded after the pre-launch period, but should be re-used and easily incorporated into an automated system.

6. Prelaunch Test (I&T) and Simulation Operations

6.1 Spacecraft Integration and Test (I&T) Support

A. Description

The I&T ground system is used to support all phases of the development, integration, and checkout of the spacecraft's subsystems and the spacecraft's instruments. The I&T ground system has two main functions; a.To provide a stimulus to the spacraft and it's instruments (i.e. Commands) and b. To monitor and evaluated the response recieved from the spacecraft (i.e. telemetry). The I&T interfaces with the spacecraft through a hardwired connection (RS-422) or through a RF interface.

B. State of the Practice at GSFC

B.1 Operator functions and Operational Systems

Typically the operator will bring up I&T ground system first in order to assure that the ground system is ready and available to support the spacecraft. The I&T ground system is usually booted up and brought up to a ready state through the use of "shell" scripts. Test commands are generated and sent to a simulator either manually or through the use of Standard Test and Operations Language (STOL) scripts to insure that the I&T system is ready. Next individual spaceacraft subsystems are carefully power on physically (either manually or through the use of automated tools like LabView). The spaceacraft/instrument engineer will then initiate a series of preplanned tests by invoking STOLS scripts to send commands and to monitor telemetry. The I&T will log the commands sent and the telemetry recieved into a buffer for additional analysis. Typical operator I&T functions include generation of test scripts (typically STOL), development of pages to monitor telemetry (using COTS tools like DataViews or Sammi, or legacy software like TPOCC display builder) and plot/trend telemetry data (using GTAS, PV-Wave or IDL). During a test pages, scripts and databases may be updated. After completion of the test the spacecraft/instrumnet is command into a preplanned state and the subsystems are phyically powered down.

Currently at GSFC there are three main systems used for I&T:

a. ASSIST - Code 730
b. TPOCC based
c. PORTS based (Hubble only)

B.2 Planned Systems

For the MIDEX missions, GSFC codes 400, 500, 600 and 700 have agreed to develop a joint I&T/MOC/SOC system. This system is under going requirement definition at the current time.

B.3 Possible Systems

A major area for advancement in the I&T area is in the capturing of the spacecraft/instrument engineer knowledge. Most spacecraft/instrument engineer's knowledge is lost before being propagated to the MOC/FOT. None of the existing I&T systems makes use of modeling, model based reasoning or knowledge based reasoning to automate the system or to capture the engineers knowledgeCurrently this knowledge is capture through the "re-use" of I&T STOL scripts, and pages in the MOC. The current I&T systems makes use of primitive scripting capabilites (i.e. STOL) which are not able adapt to non-scripted or unexpected events to automate some of their functions.

It would be highly desireable to have the spaceacraft engineers develop,verify and deliver spaceacraft subsystem and instruments models as well as pages and scripts to the MOC/FOT. The MOC/FOT would then maintain use the models to better monitor/control the spaceacraft. The MOC/FOT might take over responsibiliy for mainitaining these models after launch. the emphasis of this system would be capturing and maintain this spacecraft models.

6.2 MOC Integration Testing

A. Description

MOC integration testing focuses on verifying the integrity of the software system as a whole, and verifying the interfaces between ground system elements. The test process verifies the DMR level requirements and the products that pass between various elements of the ground system.

B. State of the Practice at GSFC

B.1 Current functions and operational systems

Simulators are the primary tool for this type of testing. Capabilities required in a simulator for this purpose include the ability to output all of the spacecraft telemetry modes and formats, receive all command modes and verify the commands, model on-board data recorders, generate instrument data formats, and model some capabilities of the on-board processor (data and memory management). The simulators used for this testing reside entirely external to the MOC environment, communicate via NASCOM blocks, and typically model some of the ground station functions. This test process is relatively labor intensive. For initial tests, support is generally required from the individual operations, test, and development teams in addition to the Integration test team. Tests are designed to exercise each of the product interfaces defined in the DMR. The content of the product is not always as robust as expected during the mission due to limited simulation capabilities, but the interface can be successfully tested.

B.2 Planned systems

Now, as the Renaissance era dawns, the interfaces between ground system software will hopefully become more in line with standard network interface protocols and in some cases evolve directly into the fold of the existing MOC architecture. The only planned modification to the existing simulators is to keep pace with the external network interfaces being implemented for MOC/network interaction.

B.3 Possible Systems

Increasing the capabilities of the simulators to include scheduling functions and the output of all station message traffic, including tracking data, would allow for a complete test exercising not only the product interfaces, but also the content of those products. A test of this nature would require sufficient time to allow all of the products in the process to be exchanged. This may require simulation of a number of passes over the course of a week.

6.3 Network and Launch Site Testing

A. Description

Network and Launch Site testing is performed to verify the capability of the end-to-end system to reliably transfer commands and telemetry to and from the spacecraft. It is used to verify communication paths, practice voice protocols, acquaint operations personnel from the various network and ground system elements with each other, the spacecraft, and operations procedures, and support the assessment of launch readiness.

B. State of the practice at GSFC

B.1 Current operations and systems.

Simulators, tapes and data generators are the primary tools for this type of testing. Capabilities required in a simulator for this purpose include the ability to output all of the spacecraft telemetry modes and formats, receive all command modes and verify the commands, model on-board data recorders, and generate instrument data formats. The tapes used for this purpose are generally telemetry tapes recorded from the spacecraft. They are converted to either digital or analog form and sent to the various stations for playback. The data generators for this type of testing provide a high level representation of the telemetry format. Unless a simulator is used at the station or launch site, these tests are generally not interactive (from the command/telemetry perspective). For SN supported spacecraft, the ETE tests can include communication with an on-orbit TDRS using the simulator in conjunction with the RF SOC.

B.2 Planned systems

The only planned modification to the existing simulators is to keep pace with the external network interfaces being implemented for MOC/network interaction. The Programmable Data Formatter is in the process of being updated and deployed to the GN and the DSN. The new system, called either the new PDF or the Programmable Telemetry Processor (PTP), will increase the data playback capability at the stations to which it is deployed. The PTP is a PC-based system that allows serial data playback from a binary file stored on CD-ROM. There is also an in-house capability to write to CD-ROM. This allows spacecraft data to be recorded from a spacecraft data flow, or an analog tape (in conjunction with the DEL) and be written to CD-ROM. These CD's can then be duplicated and distributed to the various stations. Each station can then have a catalog of data files to be played back for test purposes.

B.3 Possible Systems

There appears to be some feeling that the only station testing required is that which verifies the communication path to/from the station to the ground system. It is more important to give the station personnel hands-on training taking a pass for a specific mission with the rest of the ground system involved. This is a very beneficial exercise both for the ground system and for the station personnel. Both normal and contingency operations can be exercised. Contingency operations can be created at the station by test personnel and the station training coordinator who could fail various equipment to determine the operators ability to identify the failed element, communicate the problem to the station director, and repair the problem with the proper communication made to the rest of the ground system. The benefit of maintaining and even increasing the amount of interactive simulations at each of the sites prior to launch is the reduction of the risk associated with the first passes taken for each mission having a large element of training involved. The lead center for a mission should take responsibility for ensuring a stations ability to adequately prepare their personnel to support each mission.

C. State of the Practice at Other Organizations

D. Issues

E. Recommendations

Renaissance Operations Automation Action Team
John Welch - Draft 4/24/95

6.4 FOT Training

A. Description

FOT training is performed to increase their familiarity with the operational systems and procedures to be used during the mission. The normal and contingency procedures written by the FOT are also verified in this process.

B. State of the practice

B.1 Current operations and systems

FOT training includes numerous activities that do not overlap with the other test activities described above. The use of a high fidelity simulator that faithfully represents the spacecraft does. In addition to the capabilities listed above for integration testing, a simulator used to support FOT training is required to model the dynamic motion of the spacecraft, the effects of actuator commands, the modeling of sensor telemetry, more robust on-board processor modeling, power and thermal property models, and spacecraft communication path modeling. The simulator must also model the interaction of the various spacecraft subsystems to provide some realistic response to contingency conditions. There are currently high fidelity simulators being used for UARS, GRO, HST, XTE and SOHO. SOHO is a software only simulator that has integrated two separate Ada flight software packages into the spacecraft simulator, the others have breadboard C&DH systems integrated into them.

B.2 Planned systems

High fidelity simulators for TRMM, ACE, and LANDSAT are being developed. The ACE simulator will be a software only simulator. The TRMM simulator has a C&DH breadboard and the LANDSAT simulator may have a C&DH equivalent. The SOHO, ACE, and LANDSAT simulators are being developed together using the object-oriented paradigm to be reusable systems.

B.3 Possible Systems

It is possible and desirable to integrate the spacecraft simulator functions across the Directorate into a single architecture so each mission, or each test tool within a mission, can be derived from a common set of simulator building blocks.

C. State of the Practice at Other Organizations

D. Issues

E. Recommendations

Summary of Operations Automation Recommendations

General Recommendations

Recommendation	Section in Document	Comments
Reengineer – re-think entire space/ground operations	3.1	
Consider intelligent hybrid systems approach for mission automation rather than use of a single technology	3.1	
Use COTS and GOTS as much as possible	3.1, 3.2	
Pay particular attention to usability issues in automated systems	3.1	
Make use of innovative technology testbeds as part of the evaluation process	3.1	
Consider the spacecraft as a major component; automate it as much as possible and be aware of its impact on the ground segment	3.1	
Involve the FOT in the design, development, and review of operations automation	3.1, 3.2	
Support distributed approaches and as-needed use of centers of expertise	3.1, 4, 5	
Support the operations-by-exception paradigm	3.1	
Develop better awareness of relevant automation practices outside GSFC	3.2	
Continue ongoing efforts to automate individual software packages	4	
Automate all routine operations, including routine anomaly recognition	5	
Limit system change by building systems to be generic, flexible, and table-driven	5	

Specific Recommendations

Recommendation	Section in Document	Ops Component	Cost	Benefit
Automate routine command and control	3.2	Cmd&Ctrl	medium	high
Interface to the planning and scheduling system	3.2	Command and Control	medium	high
When both systems are operational, perform cost/benefit analysis using the SDPF vs. the FAST PPS	5	Data Collect, Proc, & Dist	low	high
Automate receipt of RUST schedules	5	Data Collect, Proc, & Dist	low	low